4. APPLICATION EXPERIMENT ON LAN BRIDGE

These experiments evaluated the performance of TCP/IP-based applications where an ISDN LAN bridge was included in the communications link to transform two remote LAN’s into a single logical LAN. TCP/IP applications involved both real-time interactive and noninteractive uses. Additionally, the communications service was based on virtual circuit or datagram service. In this experiment, each of these components was evaluated for usability and stability. A terrestrial baseline was established for evaluating changes in application performance when a satellite link was introduced.

4.1 Experiment Objectives

The experiments were intended to identify the performance issues that should be considered when a satellite link is included in the communications system. The objectives of these experiments were not intended to evaluate the COTS implementations.

4.2 Experiment Methods

A 66-MHz/486 personal computer and a Sun® workstation were used as the end systems for the LAN bridge experiments. These systems were selected because they represent commonly available workstations that were capable of sustained TCP/IP transfer rates significantly greater than could be supported by the LAN-bridge.

The experiments were conducted using the two equipment configurations illustrated in Figure 4.1. For terrestrial experiments, two workstations were connected to a local Ethernet segment in Boulder and Gaithersburg. The Ethernet segments were bridged via Combinet Interchange® LAN bridges communicating with each other via proprietary protocols over an ISDN BRI connection from a local ISDN PBX (Teleos Network Hub). The PBX’s were interconnected via PRI ISDN service from FTS2000 (Network A). A bit-error simulator (Adtech SX-12) was connected between the FTS2000 PRI and the PBX at the Boulder end of the circuit to inject errors into the datastream in both directions independently.

For ACTS-based experiments, the same two workstations were connected to the same LAN bridges and PBX’s in Boulder and Gaithersburg. The Gaithersburg PBX was connected via dedicated ISDN PRI service to a PBX in Clarksburg (COMSAT). The Boulder and Clarksburg PBX’s were interconnected via PRI ISDN service from the ACTS T1-VSAT’s in Boulder and Clarksburg. A bit-error simulator was connected between the T1-VSAT PRI and the PBX at the Boulder end of the circuit to inject errors into the datastream in both directions independently.

The bit-error simulator was used to simulate error scenarios that might be observed over a link in actual operations. Two scenarios were investigated. The first was based on a “steady-state” environment. For this scenario, the statistics of the random bit errors were uncorrelated and Gaussian distributed for the duration of the experiment. This simulates the errors caused by noise from a variety of background sources. Thresholds for usability and application failure were determined. The second scenario was based on a transient error environment that causes severe error bursts for some period. These tests were intended to determine the stability/recoverability of the applications to transient error rates. A moderate error background was used with a periodic severe burst of random errors of a fixed duration. Thresholds for recovery/failure were determined by varying the burst length and intensity.

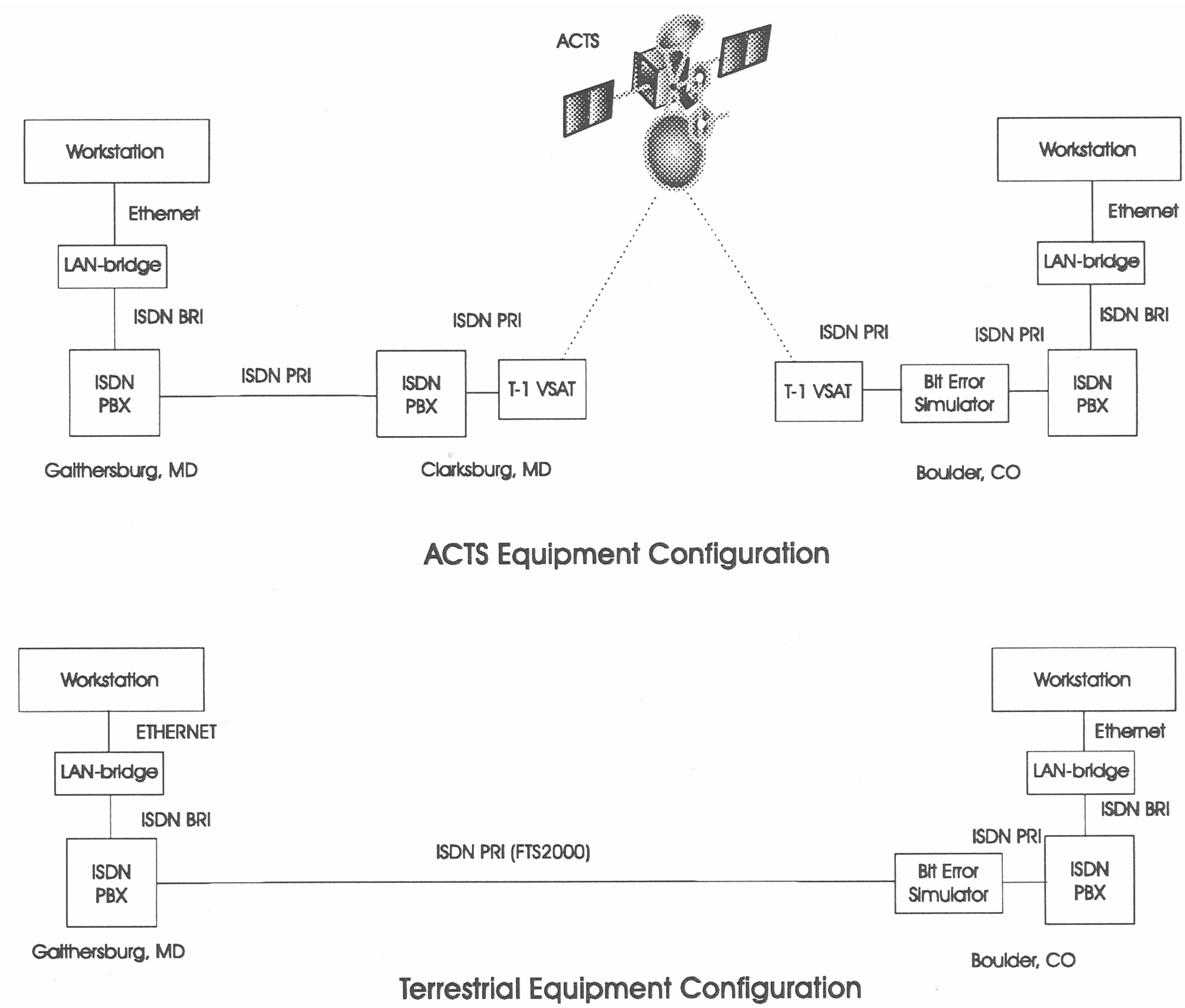

Figure 4.1. Experiment equipment configuration.

4.2.1 File Transfer Protocol

The file transfer protocol (FTP) experiments are designed to evaluate performance of bulk data transfers. These transfers are typically not time-critical, as in a real-time interactive application. However, correctness and completeness of the data are typically important.

A 278,507-byte image was used as the bulk data. To give some indication of the information that may be contained in such a transfer, the image is shown in Figure 4.2.

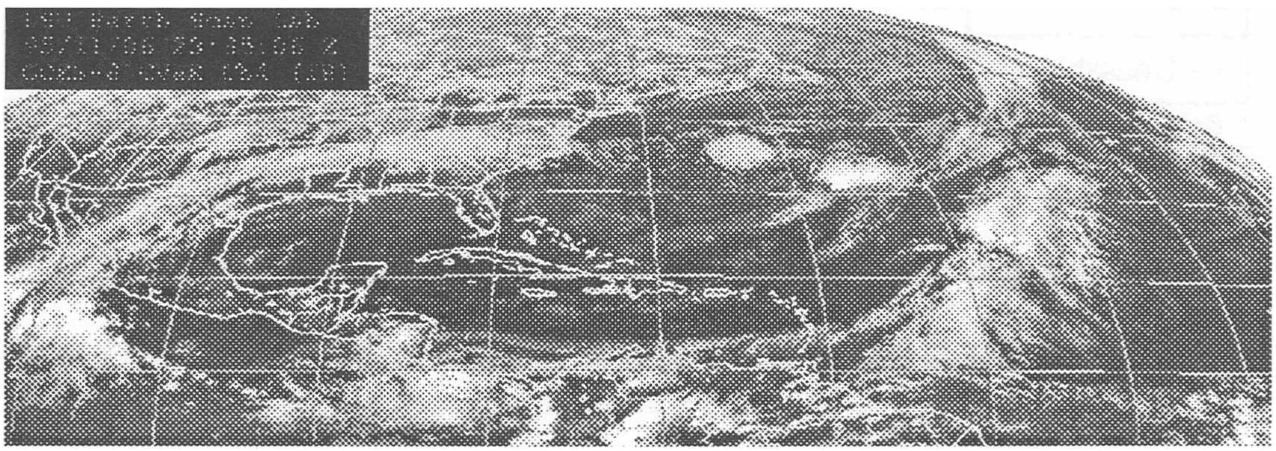

Figure 4.2. File used in FTP experiments (actual file is a color image).

4.2.2 Telnet

Telnet experiments are designed to evaluate performance of interactive keystroke-oriented applications. Such applications become "annoying" if the response time is excessively long. Correctness is important, but often not critical since rekeying can resolve the error.

4.2.3 Ping

The ping experiments are designed to evaluate the performance of datagram-oriented applications. A datagram is the underlying transport mechanism for most TCP/IP communication. These experiments determined the reliability of the datagram service by measuring the packet loss rate.

4.3 Metrics

Opinion Score (OS): An OS was used to evaluate the subjective usability for the FTP and Telnet applications. The rating scale was defined as found in Table 4.1 (fractional scores were not excluded from use).

Table 4.1. Definition of Opinion Score Values

Opinion Score	Description
5 - Excellent	Incapable of discriminating between LAN* and bridged LAN.
4 - Good	Subtle differences between LAN and bridged LAN performance.
3 - Fair	Obviously a bridged LAN, but not disturbing to the user in most cases.
2 - Poor	Somewhat disturbing differences in performance, but still usable.
1 - Unusable	Use of system is not practical or useful.

* References to "LAN" performance assume a system where expected throughput typically exceeds 1 Mb/s and ping round-trip delays of about 2 IDS.

Packet Loss Percentage: The fraction of packets that were transmitted, but not received.

Throughput: The number of bits per second (b/s) successfully transmitted to the destination.

4.4 Experimental Procedure

The following sections describe the procedures used in the FTP, ping and TELNET experiments.

4.4.1 FTP

1. Observe link signal quality via E_b/N_0 at Earth stations to verify low link BER. (A terrestrial link is assumed to have a BER less than 10^{-9}.)

2. Set BER for the experiment via the bit-error simulator (Tables 4.2 and 4.3).

3. Issue commands to initiate file transfer.

4. Record transmission statistics: elapsed time and transfer rate.

5. Check file transmitted for any errors in the data. Record number of bytes in error.

6. Assess FTP usability via subjective OS including any other observations. Record OS and observations.

Table 4.2. Steady State BER Configurations

Measurement Number	BER
1	0
2	10^{-9}
3	10^{-6}
5	10^{-5}
5	10^{-4}
6	10^{-3}
7	10^{-2}

Table 4.3. Burst BER Configurations

Measurement	Background BER	Burst BER	Burst Duration (s)	Burst Gap (s)
1	10^{-6}	10^{-2}	0.5	10
2	10^{-6}	10^{-2}	1.0	10
3	10^{-6}	10^{-2}	1.0	10
4	10^{-6}	10^{-2}	2.0	10
5	10^{-6}	10^{-2}	3.0	10
6	10^{-6}	10^{-2}	5.0	10
7	10^{-6}	10^{-2}	10.0	10
8	10^{-5}	10^{-2}	0.5	10
9	10^{-5}	10^{-2}	1.0	10
10	10^{-5}	10^{-2}	5.0	10
11	10^{-5}	10^{-2}	10.0	10

4.4.2 Telnet

1. Observe link signal quality via E_b/N_0 at Earth stations to verify low link BER. (A terrestrial link is assumed to have a BER less than 10^{-9}.)

2. Set BER for the experiment via the bit-error simulator (Tables 4.2 and 4.3).

3. Issue command to establish Telnet session.

4. Type terminal commands, check data transmitted for any errors, and record number of bytes m error.

5. Assess Telnet usability via subjective OS including any other observations. Record OS and observations.

4.4.3 Ping

1. Observe link signal quality via E_b/N_0 at Earth stations to verify low link BER. (A terrestrial link is assumed to have a BER less than 10^{-9}.)

2. Set BER for the experiment via the bit-error simulator (see Tables 4.2 and 4.3).

3. Issue commands to generate 100 pings, 64 bytes long.

4. Record transmission statistics: round-trip delay and percent packet loss.

Table 4.3 defines the set of BER configurations used in step 2 of the above procedures for burst BER configurations. These experiments characterize the transient behavior (e.g., failure/recovery) of the application in response to changes in the BER. The burst duration and the burst gap were periodic delays (i.e., not random). This permits viewing the experiment as a collection of burst events that could be observed independently to note transient behavior to a single burst event.

The background BER is the bit error rate between bursts. The burst BER is defined as the bit error rate during an error burst event. The burst gap is defined as the interval between the end of one error burst and the beginning of the next. The burst interarrival time is the sum of the burst duration and the burst gap.

4.5 Expected Results

The following summarizes the expected results for the experiments.

- Telnet and FTP usability will degrade and become unusable with increased bit error rate.
- Additional delay introduced by the satellite path may cause protocol timers to expire causing application failure.
- Undetected errors may be introduced into data transmitted.
- Satellite propagation delays may cause some difficulty in real-time Telnet response because character echos will be delayed.
- The experiments involving error bursts will characterize the transient behavior of the application to errors. Longer duration bursts are likely to cause application and/or link failure due to expiration of timers; short bursts will probably make the application unusable during the burst, but identify the recovery behavior of the system.

4.6 Results

Figure 4.3 illustrates the throughput observations for FTP over both terrestrial and ACTS configurations. These scores were based on experiments with a BER defined as the mean of Gaussian bit error arrival times, which simulates errors from many independent noise sources. The statistics for these errors are time-invariant for the duration of the experiment. These experiments describe the steady-state application performance for a given environment.

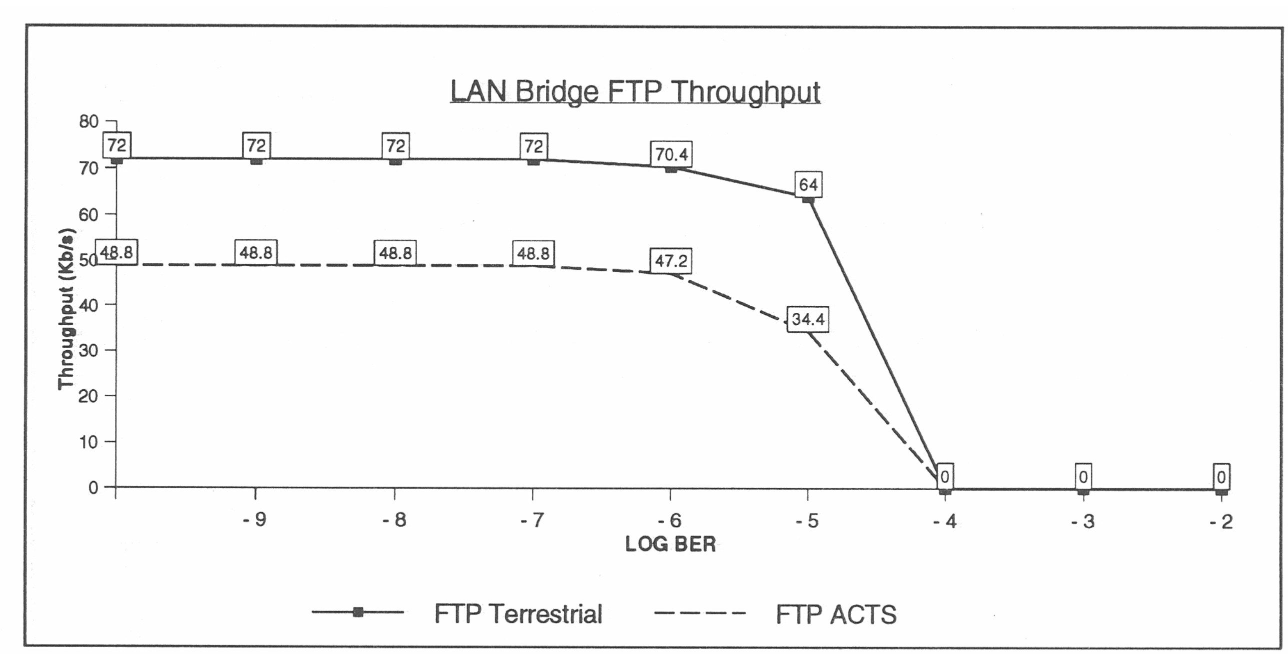

Figure 4.3. LAN bridge FTP throughput results.

Table 4.4 summarizes the recovery behavior of FTP over a LAN bridge in the presence of error bursts over a terrestrial line.

Table 4.4. Burst BER Results Over the Terrestrial Line

Background BER	Burst BER	Burst Duration (s)	Burst Gap (s)	Behavior
10^{-6}	10^{-2}	0.5	10	Recovery
10^{-6}	10^{-2}	1.0	10	Recovery
10^{-6}	10^{-2}	2.0	10	Recovery
10^{-6}	10^{-2}	3.0	10	Failure
10^{-6}	10^{-2}	5.0	10	Failure
10^{-6}	10^{-2}	10.0	10	Failure
10^{-5}	10^{-2}	0.5	10	Recovery
10^{-5}	10^{-2}	1.0	10	Recovery
10^{-5}	10^{-2}	2.0	10	Recovery
10^{-5}	10^{-2}	3.0	10	Failure
10^{-5}	10^{-2}	5.0	10	Failure
10^{-5}	10^{-2}	10.0	10	Failure

Table 4.5 summarizes the recovery behavior of FTP over a LAN bridge in the presence of error bursts over ACTS.

Figure 4.4 illustrates the usability opinion scores for the FTP, Telnet, and Ping experiments in the ACTS configuration.

Table 4.5. Burst BER Results Over ACTS

Background BER	Burst BER	Burst Duration (s)	Burst Gap (s)	Behavior
10^{-6}	10^{-2}	0.5	10	Recovery
10^{-6}	10^{-2}	1.0	10	Recovery
10^{-6}	10^{-2}	2.0	10	Recovery
10^{-6}	10^{-2}	3.0	10	Recovery
10^{-6}	10^{-2}	5.0	10	Failure
10^{-6}	10^{-2}	10.0	10	Failure
10^{-5}	10^{-2}	0.5	10	Recovery
10^{-5}	10^{-2}	1.0	10	Recovery
10^{-5}	10^{-2}	5.0	10	Failure
10^{-5}	10^{-2}	10.0	10	Failure

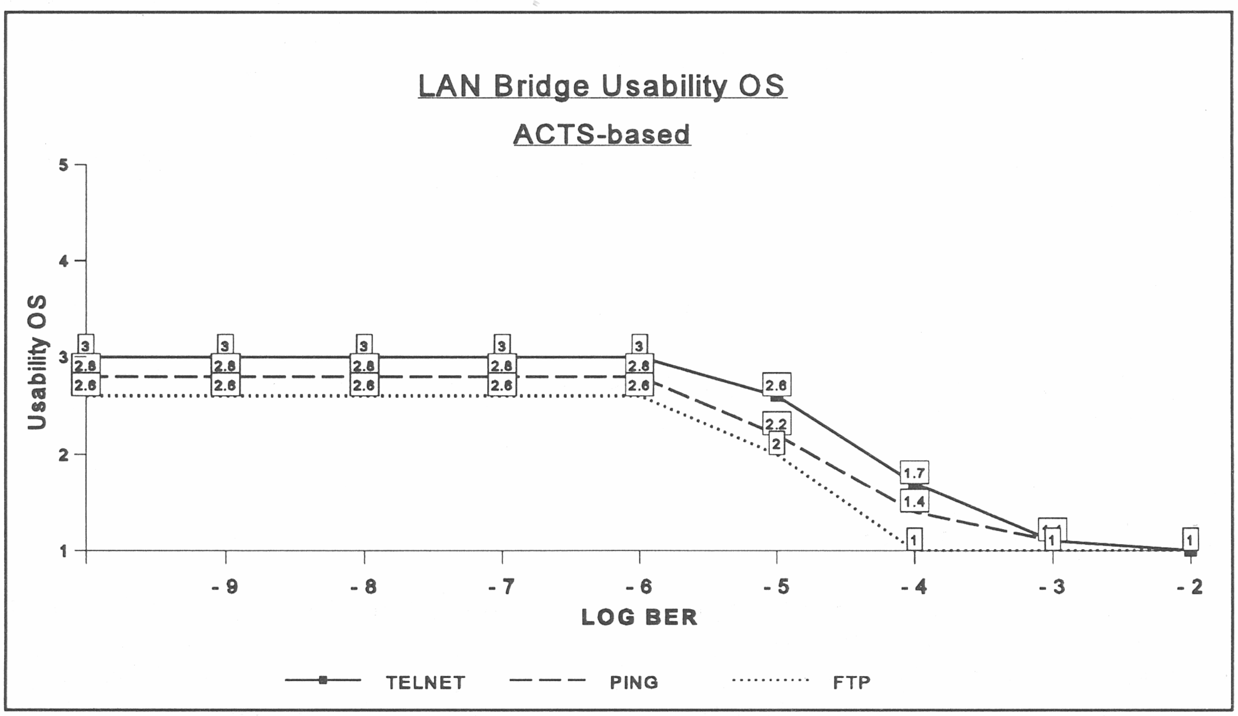

Figure 4.4. LAN bridge usability over ACTS.

Figure 4.5 illustrates the usability opinion scores for the FTP, Telnet, and Ping experiments in the terrestrial configuration.

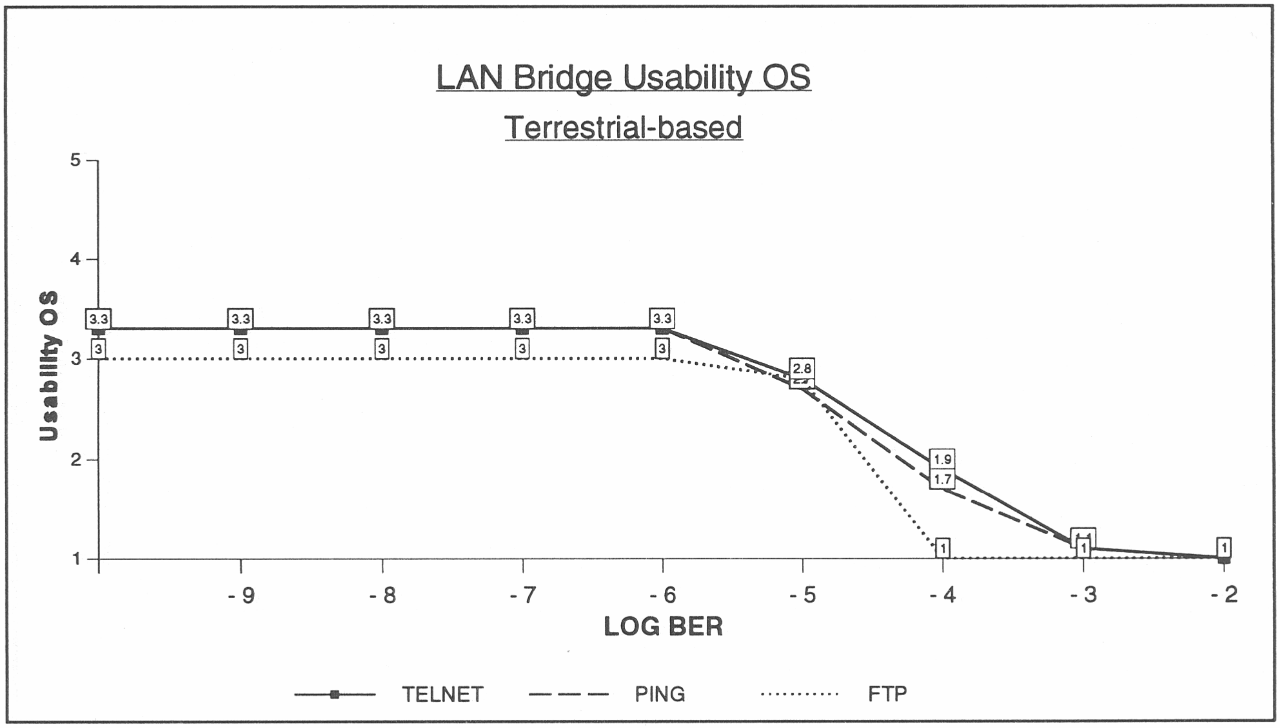

Figure 4.5. LAN bridge usability opinion scores for the terrestrial line.

Figure 4.6 illustrates the percent packet loss for repeated pings as a function of BER for both terrestrial and ACTS configurations.

4.7 Analysis

All applications tested began to degrade with error rates greater than 10^{-6} and were not useful for error rates greater than 10^{-3}.

4.7.1 File Transfer Protocol

The curves for FTP throughput as a function of BER over both terrestrial and ACTS configurations exhibited parallel behavior. The throughput over ACTS was consistently less than that over a terrestrial line. This difference was due to the additional propagation delay causing throttling of the end-to-end protocols of the LAN bridge and FTP. This was confirmed through additional experiments conducted with a delay simulator and no additional bit errors. No degradation of throughput was observed for one-way delays less than about 100 ms.

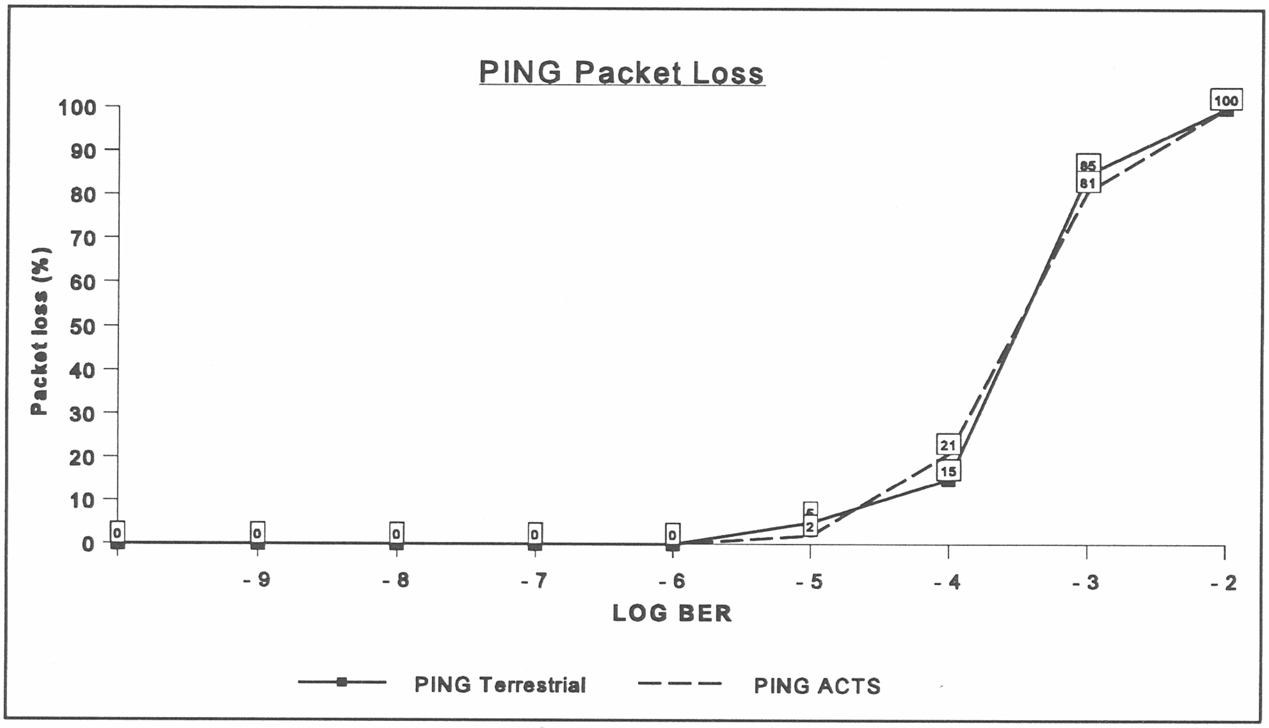

Figure 4.6. Ping packet loss results.

Other supplemental tests revealed that FTP becomes unstable with a BER of about 10^{-4} or greater. The burst test revealed that FTP would recover if the BER improved to 10^{-5} or less within 5 s. If the burst lasted longer, the transfer failed independent of the error density before, during or after the burst.

There were no errors in the transmitted data for any configuration in which the transmission completed normally. Abnormal termination resulted in a partial transfer of correct data.

The differences in the opinion scores for terrestrial and ACTS configurations were insignificant. Lower opinions resulted from bit errors causing extremely long transfer times, many times larger than that on an error-free connection. The main factor in usability was successful transmission, not differences in transmission speed.

4.7.2 Telnet

Propagation delay in ACTS experiments caused some reduction in the opinion scores for Telnet, which resulted from increased delay for character echo. However, the character echo became significantly larger for a BER in excess of 10^{-4}. BER was the major factor that caused unusability. No transmission errors were observed in the echoed characters for any keystrokes, at any BER.

4.7.3 Ping

The ping experiments indicated insignificant packet loss differences between terrestrial and ACTS configurations. The packet loss statistics were only a function of BER.

4.8 Interpretations

1. BER, not delay, is the principal factor in LAN bridge usability. The data indicate that all applications used with a LAN bridge began to degrade with a BER in excess of 10^{-6} and became essentially unusable with a BER of 10^{-3}. The usability scores for satellite versus terrestrial communications services were essentially identical, indicating that satellite delay was not a significant factor for usability.

However, FTP throughput was impaired by the additional satellite delay at all error rates. This appears to be due to acknowledgment window sizes in the TCP/IP protocol and/or the LAN bridge protocol. This could be addressed through modifications in the protocols, as described in Section 5, to improve performance in the presence of delay. Experiments indicated that one-way delays less than 100 ms did not have any impact on throughput using the current protocols.

A maximum BER of 10^{-6} is recommended for reliable LAN bridge service.

2. Additional delay due to the satellite is an important factor in highly interactive activities. While the additional delay of a satellite link is a minimal problem for file transfer and datagram delivery (ping), highly interactive uses (Telnet) become increasingly difficult with increasing frequency of interaction. If keystrokes are echoed from the remote system, the delay can become disturbing to a reasonably fast typist. This also could be a problem for other interactive applications such as remote graphic-based applications.

3. While additional delay due to satellite reduces FTP throughput, a high BER makes FTP unusable. While FTP throughput was reduced as a result of the additional satellite delay, FTP usability was impacted only minimally because of the noninteractive nature of bulk file transfers. The decreased performance was not significant to the user due to the already relatively long transfer time via terrestrial service. However, FTP was rendered unusable with a BER of 10^{-4} or greater, independent of the presence of a satellite.

4. Terrestrial communications links may fail when sustained, severe bit errors are present. Data transmitted through the public terrestrial network with a BER in excess of 10^{-3} that persists for several seconds resulted in lost connections. However, the applications themselves, except FTP, were able to remain stable with higher error rates when the errors did not propagate through the network, but were generated locally. This behavior may be attributed to an administrative decision in the terrestrial network to terminate connections that have persistent errors.

FTP appeared to fail with severe, sustained error bursts due to expiration of FTP protocol timers during these bursts.

5. Optimization of end-to-end protocols for channels with high propagation delay is needed for efficient use with satellites. The FTP experiments indicated that propagation delays were causing degraded performance over a satellite channel. However, the degradation did not occur for delays less than 100 ms. This indicates that protocol parameters, such as window sizes, might be adjusted to improve performance over channels with longer delays. The protocol-oriented experiments, reported in Section 5, address this issue.